

Charge and CP asymmetries of B_q meson in unparticle physics

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Abstract

Recently the DØ Collaboration reported an observation of like-sign charge asymmetry (CA), which is about 3.2σ deviation from the standard model (SM) prediction. Inspired by the observation we investigate the scalar unparticle effects, under the color charge of $SU(3)_c$ symmetry, in the CP violation in neutral B meson oscillations as well as the dispersive and absorptive parts of $\bar{B}_q \leftrightarrow B_q$ transition, which can be related to the CA directly. In order to illustrate the peculiar properties of unparticle, our analysis is carried out in two scenarios for the right-handed section: (I) $\lambda_R = \lambda_L$ and $U_D^R = U_D^L$, where $\lambda_{L,R}$ and $U_D^{L,R}$ are the couplings and flavor mixing matrix of left- and right-handed section, respectively; (II) $\lambda_R \gg \lambda_L$ and U_D^R is completely a free parameter. In scenario I we found that the wrong- and like-sign CA cannot be changed significantly for a SM-like CP violating source because of the strong constraint of Δm_{B_d} . Contrarily, in scenario II we can figure out the parameter space in which the CA can be enhanced to the value observed by DØ with the constraint of Δm_{B_s} due to the enhancement of Γ_{12}^s . In the parameter space we obtained, the correlation between $\Delta\Gamma^s$ and ϕ_s is consistent with the current CDF and DØ results.

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DØ Collaboration of Tevatron recently observed the like-sign charge asymmetry (CA), defined as [1]

$$A_{s\ell}^b = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} \quad (1)$$

with $N_b^{++(-)}$ being the number of events that b - and \bar{b} -hadrons semileptonically decay into two positive (negative) muons. The measured value in the dimuon events is [1]

$$A_{s\ell}^b = [-9.57 \pm 2.51(\text{stat}) \pm 1.46(\text{syst})] \times 10^{-3}. \quad (2)$$

Surprisingly, the observation is about 3.2σ away from the SM prediction [1, 2] of

$$A_{s\ell}^b(\text{SM}) = [-2.3_{-0.6}^{+0.5}] \times 10^{-4}.$$

Since the CA is directly related to CP violation (CPV) in $B_{d,s}$ -meson oscillations and associated with dispersive (M_{12}^q) and absorptive (Γ_{12}^q) parts of $\bar{B}_q \leftrightarrow B_q$ transition, the large deviations from the SM could be ascribed to new CP phases in $b \rightarrow d$ and $b \rightarrow s$ transitions [3–33].

Inspired by the anomalous CA, we study the contributions of scale or conformal invariant stuff, which is known as unparticle [34, 35]. The unique character of unparticle is its peculiar phase appearing in the off-shell propagator with positive squared transfer momentum [34–37]. Due to CP invariance, the imaginary part of the phase factor leads to the absorptive effect of a process. In the case of $B_q - \bar{B}_q$ mixing, not only can the M_{12}^q but also Γ_{12}^q be affected [27, 37, 38]. It is interesting to investigate whether the influence of unparticle on M_{12}^q and Γ_{12}^q could enhance the phase $\phi_q = \arg(-M_{12}^q/\Gamma_{12}^q)$ which is directly related to the CA. In order to make the production of scale invariant stuff be efficient at Large Hadron Collider (LHC), we investigate the unparticle that carries the color charges of $SU(3)_c$ symmetry [39].

To understand the like-sign CA, we start with discussing the relevant phenomena. With strong interaction eigenbasis, the Hamiltonian for unstable \bar{B}_q and B_q states is written as

$$\mathbf{H} = \mathbf{M}^{\mathbf{q}} - i \frac{\mathbf{\Gamma}^{\mathbf{q}}}{2}, \quad (3)$$

where $\mathbf{\Gamma}^{\mathbf{q}}(\mathbf{M}^{\mathbf{q}})$ denotes the absorptive (dispersive) part of the $\bar{B}_q \leftrightarrow B_q$ transition. Accordingly, the time-dependent wrong-sign CA in semileptonic B_q decays is defined and given [40]

by

$$a_{s\ell}^q = \frac{\Gamma(\bar{B}_q(t) \rightarrow \ell^+ X) - \Gamma(B_q(t) \rightarrow \ell^- X)}{\Gamma(\bar{B}_q(t) \rightarrow \ell^+ X) + \Gamma(B_q(t) \rightarrow \ell^- X)},$$

$$\approx \text{Im} \left(\frac{\Gamma_{12}^q}{M_{12}^q} \right). \quad (4)$$

Here, the assumption $\Gamma_{12}^q \ll M_{12}^q$ in B_q system has been used. Intriguingly, $a_{s\ell}^q$ indeed is not a time dependent quantity. The SM predictions [2] are

$$a_{s\ell}^d(\text{SM}) = (-4.8_{-1.2}^{+1.0}) \times 10^{-4}, \quad a_{s\ell}^s(\text{SM}) = (2.06 \pm 0.57) \times 10^{-5},$$

while the current data [41, 42] are

$$a_{s\ell}^d(\text{Exp}) = (-4.7 \pm 4.6) \times 10^{-3}, \quad a_{s\ell}^s(\text{Exp}) = (-1.7 \pm 9.1) \times 10^{-3}.$$

The relation between the wrong and like-sign CAs is defined and expressed [1, 43] by

$$A_{s\ell}^b = \frac{\Gamma(b\bar{b} \rightarrow \ell^+ \ell^+ X) - \Gamma(b\bar{b} \rightarrow \ell^- \ell^- X)}{\Gamma(b\bar{b} \rightarrow \ell^+ \ell^+ X) + \Gamma(b\bar{b} \rightarrow \ell^- \ell^- X)},$$

$$= 0.506(43)a_{s\ell}^d + 0.494(43)a_{s\ell}^s. \quad (5)$$

Clearly, the like-sign CA is associated with the wrong-sign CAs of B_d and B_s systems. Since the direct measurements of $a_{s\ell}^d$ and $a_{s\ell}^s$ are still quite uncertain, either $b \rightarrow d$ or $b \rightarrow s$ transition or both could be the source of unexpected large $A_{s\ell}^b$.

In order to explore the new physics effects, we write the transition matrix elements as $M_{12}^q = M_{12}^{q,\text{SM}} + M_{12}^{q,\text{NP}}$ and $\Gamma_{12}^q = \Gamma_{12}^{q,\text{SM}} + \Gamma_{12}^{q,\text{NP}}$ and parameterize them as

$$M_{12}^q = M_{12}^{q,\text{SM}} \Delta_q^M e^{i\phi_q^\Delta},$$

$$\Gamma_{12}^q = \Gamma_{12}^{q,\text{SM}} \Delta_q^\Gamma e^{i\gamma_q^\Delta} \quad (6)$$

with

$$M_{12}^{q,\text{SM[NP]}} = \left| M_{12}^{q,\text{SM[NP]}} \right| e^{2i\bar{\beta}_q[\theta_q^{\text{NP}}]}, \quad \Gamma_{12}^{q,\text{SM}} = \left| \Gamma_{12}^{q,\text{SM[NP]}} \right| e^{i\gamma_q^{\text{SM[NP]}}},$$

$$\Delta_q^M = \left| 1 + r_q^M e^{2i(\theta_q^{\text{NP}} - \bar{\beta}_q)} \right|, \quad r_q^M = \frac{|M_{12}^{q,\text{NP}}|}{|M_{12}^{q,\text{SM}}|},$$

$$\Delta_q^\Gamma = \left| 1 + r_q^\Gamma e^{i(\gamma_q^{\text{NP}} - \gamma_q^{\text{SM}})} \right|, \quad r_q^\Gamma = \frac{|\Gamma_{12}^{q,\text{NP}}|}{|\Gamma_{12}^{q,\text{SM}}|},$$

$$\tan \phi_q^\Delta = \frac{r_q^M \sin 2(\theta_q^{\text{NP}} - \bar{\beta}_q)}{1 + r_q^M \cos 2(\theta_q^{\text{NP}} - \bar{\beta}_q)}, \quad \tan \gamma_q^\Delta = \frac{r_q^\Gamma \sin(\gamma_q^{\text{NP}} - \gamma_q^{\text{SM}})}{1 - r_q^\Gamma \cos(\gamma_q^{\text{NP}} - \gamma_q^{\text{SM}})}. \quad (7)$$

The phases appearing above stand for weak CP violating phases. We note that although $\bar{\beta}_q$ is not a conventional notation for the CP phase of the SM denoted by β_q , their relationship could be read by $\bar{\beta}_d = \beta_d$ and $\bar{\beta}_s = -\beta_s$. Using $\phi_q = \arg(-M_{12}^q/\Gamma_{12}^q)$, the wrong-sign CA in Eq. (4) with new physics effects on Γ_{12}^q and M_{12}^q could be given as

$$a_{s\ell}^q = \frac{\Delta_q^\Gamma}{\Delta_q^M} \frac{\sin \phi_q}{\sin \phi_q^{\text{SM}}} a_{s\ell}^q(\text{SM}) \quad (8)$$

with $\phi_q^{\text{SM}} = 2\bar{\beta}_q - \gamma_q^{\text{SM}}$ and $\phi_q = \phi_q^{\text{SM}} + \phi_q^\Delta - \gamma_q^\Delta$. Furthermore, the mass and rate differences between heavy and light B mesons could be expressed by

$$\begin{aligned} \Delta m_{B_q} &= 2|M_{12}^q|, \\ \Delta \Gamma^q &= \Gamma_L - \Gamma_H = 2|\Gamma_{12}^q| \cos \phi_q. \end{aligned} \quad (9)$$

Another type of the time-dependent CP asymmetry (CPA) is associated with the definite CP in the final state, defined by [40]

$$\begin{aligned} A_{f_{CP}}(t) &\equiv \frac{\Gamma(\bar{B}_q(t) \rightarrow f_{CP}) - \Gamma(B_q(t) \rightarrow f_{CP})}{\Gamma(\bar{B}_q(t) \rightarrow f_{CP}) + \Gamma(B_q(t) \rightarrow f_{CP})}, \\ &= S_{f_{CP}} \sin \Delta m_{B_q} t - C_{f_{CP}} \cos \Delta m_{B_q} t, \\ S_{f_{CP}} &= \frac{2Im\lambda_{f_{CP}}}{1 + |\lambda_{f_{CP}}|^2}, \quad C_{f_{CP}} = \frac{1 - |\lambda_{f_{CP}}|^2}{1 + |\lambda_{f_{CP}}|^2} \end{aligned} \quad (10)$$

with

$$\lambda_{f_{CP}} = \left(\frac{M_{12}^{B_q^*}}{M_{12}^{B_q}} \right)^{1/2} \frac{A(\bar{B} \rightarrow f_{CP})}{A(B \rightarrow f_{CP})}, \quad (11)$$

where f_{CP} denotes the final CP eigenstate, $S_{f_{CP}}$ and $C_{f_{CP}}$ are the so-called mixing-induced and direct CPAs, respectively. Clearly, beside the phases in the $\Delta B = 2$ processes, the mixing-induced CPA is also related to the phase in the $\Delta B = 1$ process. Nevertheless, since the new effects on the decays $B_d \rightarrow J/\Psi K_S$ and $B_s \rightarrow J/\Psi \phi$ are small, the CPAs could be simplified as

$$\begin{aligned} S_{J/\Psi K_S} &\equiv \sin 2\bar{\beta}_{J/\Psi K_S} \approx \sin(2\bar{\beta}_d + \phi_d^\Delta), \\ S_{J/\Psi \phi} &\equiv \sin 2\bar{\beta}_s^{J/\Psi \phi} \approx \sin(2\bar{\beta}_s + \phi_s^\Delta). \end{aligned} \quad (12)$$

After introducing the relevant physical observables, we begin studying the effects of colored scalar unparticle. Since there is no well established approach to give a full theory for unparticle interactions, we study the topic from the phenomenological viewpoint. In order

to avoid fine-tuning the parameters for flavor changing neutral currents (FCNCs) at tree level, we assume that the unparticle only couples to the third generation of quarks before electroweak symmetry breaking. Hence, the interactions obeying the SM gauge symmetry are expressed by

$$\frac{1}{\Lambda_U^{d_U}} \left[\lambda_R \bar{q}'_R \gamma_\mu T^a q'_R \partial^\mu \mathcal{O}_U^a + \lambda_L \bar{Q}_L \gamma_\mu T^a Q_L \partial^\mu \mathcal{O}_U^a \right], \quad (13)$$

where $\lambda_{R,L}$ are dimensionless free parameters, $q'_R = t_R, b_R$, $Q_L^T = (t, b)_L$, $\{T^a\} = \{\lambda^a/2\}$ are the $SU(3)_c$ generators (where λ^a are the Gell-Mann matrices) normalized by $\text{tr}(T^a T^b) = \delta^{ab}/2$, Λ_U is the scale below which the unparticle is formed. The power d_U is determined from the effective interaction of Eq. (13) in four-dimensional space-time when the dimension of the colored unparticle \mathcal{O}_U^a is taken as d_U . Since we only concentrate on the phenomena of down type quarks, the associated pieces are formulated by

$$\bar{D} \gamma_\mu (\mathbf{X}_R P_R + \mathbf{X}_L P_L) T^a D \partial^\mu \mathcal{O}_U^a, \quad (14)$$

in which $D^T = (d, s, b)$, $\mathbf{X}_{R(L)}$ is a 3×3 diagonal matrix and $\text{diag}(\mathbf{X}_{R(L)}) = (0, 0, \lambda_{R(L)}/\Lambda_U^{d_U})$. After spontaneous symmetry breaking of electroweak symmetry, we need to introduce two unitary matrices $U_D^{R,L}$ to diagonalize the mass matrix of down type quarks. In terms of physical eigenstates and using the equations of motion, the interactions for $b - q - \mathcal{O}_U^a$ could be written as

$$\mathcal{L}_{bq\mathcal{O}_U^a} = \frac{m_b}{\Lambda_U^{d_U}} \bar{q} (f_{qb}^R P_L + f_{qb}^L P_R) T^a b \mathcal{O}_U^a + h.c., \quad (15)$$

where $q = d, s$, the mass of light quark has been neglected and $f_{qb}^\chi = \lambda_\chi (U_D^\chi)_{qb} (U_D^{\chi*})_{bb}$ with $\chi = R, L$.

By following the scheme shown in Ref. [44], the propagator of the colored scalar unparticle is written as

$$\int d^4 x e^{-ik \cdot x} \langle 0 | T \mathcal{O}^a(x) \mathcal{O}^b(0) | 0 \rangle = i \frac{C_S \delta^{ab}}{(-k^2 - i\epsilon)^{2-d_U}} \quad (16)$$

with

$$C_S = \frac{A_{d_U}}{2 \sin d_U \pi},$$

$$A_{d_U} = \frac{16\pi^{5/2}}{(2\pi)^{2d_U}} \frac{\Gamma(d_U + 1/2)}{\Gamma(d_U - 1)\Gamma(2d_U)}. \quad (17)$$

Combining Eqs. (15) and (16), the four fermion interaction for B_q oscillation is given by

$$\mathcal{H} = \frac{C_S}{2m_b^2} \left(\frac{m_b^2}{\Lambda_U^2} \right)^{d_U} f_{qb}^2 e^{-id_U \pi} (\bar{q} T^a b)^2. \quad (18)$$

For estimating the transition matrix elements, we employ the vacuum insertion method and the results are

$$\begin{aligned} \langle \bar{B}_q | \bar{q} P_{R(L)} b \bar{q} P_{R(L)} b | B_q \rangle &\approx -\frac{5}{24} m_{B_q} f_{B_q}^2, \\ \langle \bar{B}_q | \bar{q} P_R b \bar{q} P_L b | B_q \rangle &\approx \frac{7}{24} m_{B_q} f_{B_q}^2, \\ \langle \bar{B}_q | \bar{q}_\alpha P_{R(L)} b_\beta \bar{q}_\beta P_{R(L)} b_\alpha | B_q \rangle &\approx \frac{1}{24} m_{B_q} f_{B_q}^2, \\ \langle \bar{B}_q | \bar{q}_\alpha P_R b_\beta \bar{q}_\beta P_L b_\alpha | B_q \rangle &\approx \frac{5}{24} m_{B_q} f_{B_q}^2 \end{aligned} \quad (19)$$

where the approximation $m_b \sim m_{B_q}$ is used and f_{B_q} is the decay constant of B_q meson. As a consequence, the dispersive and absorptive parts of $\bar{B}_q \leftrightarrow B_q$ in the unparticle physics are found by

$$\begin{aligned} H_{12}^U &= M_{12}^{q,U} - i \frac{\Gamma_{12}^{q,U}}{2}, \\ \text{where } M_{12}^{q,U} &= \cos(d_U \pi) h_U^q, \quad \Gamma_{12}^{q,U} = 2 \sin(d_U \pi) h_U^q, \end{aligned} \quad (20)$$

with

$$h_U^q = \frac{C_S}{18} (f_{qb}^R + f_{qb}^L)^2 \left(\frac{m_{B_q}^2}{\Lambda_U^2} \right)^{d_U} \frac{f_{B_q}^2}{m_{B_q}}. \quad (21)$$

For comparison, we also summarize the formulae of the SM as follows [40]:

$$\begin{aligned} M_{12}^{q,SM} &= \frac{G_F^2 m_W^2}{12\pi^2} \eta_B m_{B_q} f_{B_q}^2 \hat{B}_q (V_{tq}^* V_{tb})^2 S_0(x_t), \\ \Gamma_{12}^{q,SM} &\approx \frac{3\pi}{2} \left(\frac{m_b^2}{m_W^2} \right) \frac{M_{12}^{q,SM}}{S_0(x_t)} \left[1 + \frac{V_{cq}^* V_{cb}}{V_{tq}^* V_{tb}} O(m_c^2/m_b^2) \right] \end{aligned} \quad (22)$$

with $S_0(x_t) = 0.784x_t^{0.76}$, $x_t = (m_t/m_W)^2$ and $\eta_B \approx 0.55$ is the QCD correction to $S_0(x_t)$.

In the considering model, in addition to the scale dimension d_U , the couplings $\lambda_{R,L}$ and the scale Λ_U that are associated with unparticle, the flavor mixing elements $(U_D^\chi)_{qb}(U_D^\chi)^*_{bb}$ in f_{qb}^χ are also free parameters. Following the Cabibbo-Kobayashi-Maskawa (CKM) matrix defined by $V = U_U^L U_D^{L\dagger}$, indeed $(U_D^L)_{qb} = V_{tq}^*$ when we choose the convention $U_U^L = 1$. If we take the CKM matrix as inputs, then the right-handed flavor mixing element $(U_D^R)_{qb}$ is the

TABLE I: Experimental data and numerical inputs for the parameters in the SM.

\bar{V}_{td}	$\bar{\beta}_d$	\bar{V}_{ts}	$\bar{\beta}_s$
$8.51(22) \times 10^{-3}$	0.384 ± 0.014	$-4.07(22) \times 10^{-2}$	-0.018 ± 0.001
$f_{B_d} \sqrt{\bar{B}_d}$	$f_{B_s} \sqrt{\bar{B}_s}$	f_{B_d}	f_{B_s}
$(216 \pm 15) \text{ MeV}$	$(266 \pm 18) \text{ MeV}$	$190 \pm 13 \text{ MeV}$	$231 \pm 15 \text{ MeV}$
$(\Delta m_{B_d})^{\text{Exp}}$	$(\Delta m_{B_s})^{\text{Exp}}$	ϕ_d^{SM}	ϕ_s^{SM}
$0.507 \pm 0.005 \text{ ps}^{-1}$	$17.77 \pm 0.12 \text{ ps}^{-1}$	$-0.091^{+0.026}_{-0.038}$	$(4.2 \pm 1.4) \times 10^{-3}$

only free parameter. Therefore, to illustrate the peculiar properties of unparticle, we study two scenarios for $\lambda_{R,L}$ and U_D^R : (I) $\lambda_R = \lambda_L = \lambda_U$ and $U_D^R = U_D^L = V^\dagger$ (i.e. $f_{qb}^R = f_{qb}^L$); (II) $\lambda_L \ll \lambda_R$ and U_D^R is unknown (i.e. $f_{qb}^L \ll f_{qb}^R$). In scenario I, the couplings of unparticle to fermions are vector-like. In scenario II, since the behavior of left-handed couplings is similar to the scenario I, for illustrating the influence of right-handed couplings we set $\lambda_L \ll \lambda_R$. For simplicity, in the numerical estimates we take $\Lambda_U = 1 \text{ TeV}$.

For numerical calculations and constraints, we list the useful values in Table I, where the relevant CKM matrix element $V_{tq} = \bar{V}_{tq} \exp(-i\bar{\beta}_q)$ is obtained from the UTfit Collaboration [45], the decay constant of B_q is referred to the result given by the HPQCD Collaboration [46] and the value of ϕ_q^{SM} is from Ref. [2]. The CDF and DØ average values of $\Delta\Gamma^s = [-0.163, 0.163]$ and $\phi_s = [-1.35, -0.20] \cup [-2.94, -1.77]$ with 90% confidence level (CL) are from Ref. [41]. Other inputs are quoted from the particle data group (PDG) [40]. As a result, we obtain $|M_{12}^{d,\text{SM}}| = 0.253 \text{ ps}^{-1}$, $|M_{12}^{s,\text{SM}}| = 8.90 \text{ ps}^{-1}$. In addition, according to the results in Ref. [2], we also know $\Gamma_{12}^{d,\text{SM}} \approx -1.3 \times 10^{-3} \exp[i(2\beta_d - \phi_d^{\text{SM}})] \text{ ps}^{-1}$ and $\Gamma_{12}^{s,\text{SM}} \approx -0.048 \exp[i(2\beta_s - \phi_s^{\text{SM}})] \text{ ps}^{-1}$.

We first discuss the situation in scenario I, i.e. the case with $f_{qb}^R = f_{qb}^L$. Due to $U_{qb}^R = U_{qb}^L = V_{tq}^*$, the CP phase for $b \rightarrow q$ transition in unparticle exchange is the same as that in the SM. Therefore, the influence of unparticle on CPAs of $b \rightarrow s$ transition is small and insignificant. Because λ_U and d_U are only the free parameters, it is interesting to see if the unparticle could have a large effect on the wrong-sign CA. At first, we only consider the constraint from the time-dependent CPA of B_d which is formulated in Eqs. (10) and (12) and measured with $S_{J/\Psi K_S} = 0.655 \pm 0.0244$ [41]. Taking the data of $S_{J/\Psi K_S}$ with 2σ errors as the constraint, we find that $A_{s\ell}^b < -10 \times 10^{-4}$ could be archived. The allowed region

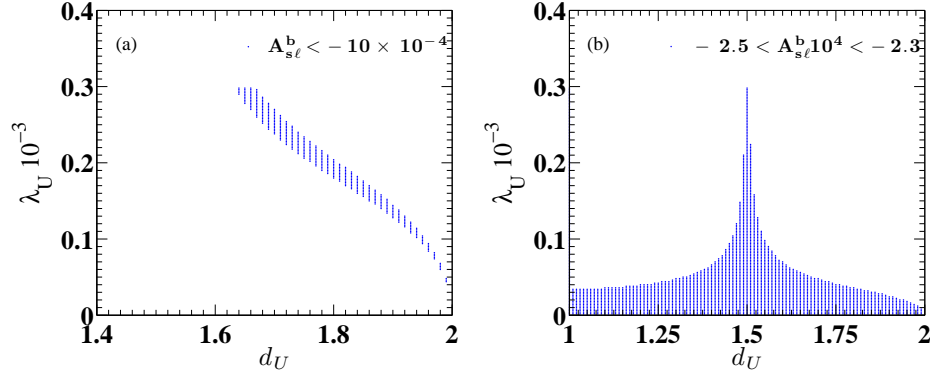


FIG. 1: The allowed range of λ_U and d_U constrained by (a) $S_{J/\Psi K_S}$ and (b) Δm_{B_d} , where the available range of $A_{s\ell}^b$ is (a) less than -10×10^{-4} and (b) within $(-2.5, -2.3) \times 10^{-4}$.

for λ_U and d_U is shown in Fig. 1(a). Unfortunately, the enhancement on the magnitude of $A_{s\ell}^b$ is suppressed when we include the constraint from the measurement of Δm_{B_d} . Taking the $(\Delta m_{B_d})^{\text{Exp}}$ with 2σ errors as the constraint, we find that the resulted like-sign CA is close to the SM prediction. The allowed region of the parameters constrained by Δm_{B_d} are presented in Fig. 1(b), where the available range for like-sign CA is $-2.5 < A_{s\ell}^b 10^4 < -2.3$. We see clearly that if the CP violating source is SM-like, by the strong constraint of Δm_{B_d} , the wrong- and like-sign CA cannot be changed significantly.

Next, we study the phenomena in scenario II. As stated early, the effects of left-handed coupling are similar to the case of scenario I, in order to display the peculiar property of unparticle, we set $\lambda_L \ll \lambda_R$ so that $f_{qb}^L \ll f_{qb}^R$. Additionally, since Δm_{B_d} and $S_{J/\Psi K_S}$ will give a strong constraint on the parameters for $b \rightarrow d$ transition [8], here we only concentrate on the phenomena associated with $b \rightarrow s$ transition. Due to λ_R and U_D^R being unknown, we use complex f_{sb}^R as the variable. In order to simplify the analysis, we will choose some specific values for $|f_{sb}^R|$ and vary the phase $\theta_U = \arg(f_{sb}^R)$ within $[0, \pi]$. The results of $[-\pi, 0]$ are expected to be similar to those in $[0, \pi]$. Consequently, with 2σ errors of $(\Delta m_{B_s})^{\text{Exp}}$, we display the constraint on θ_U and d_U in Fig. 2, where the figure (a)-(d) respectively corresponds to $|f_{sb}^R| = (4, 8, 12, 16) \times 10^{-6}$ and the scatters represent the bound given by Δm_{B_s} . In terms of Eqs. (5) and (8), we plot $-100 \leq A_{s\ell}^b 10^4 \leq -10$ which is induced by the unparticle in Fig. 2. We find that with $|f_{sb}^R| = 4 \times 10^{-6}$, the enhanced like-sign CA could occur at $1 < d_U < 1.1$ with $2.2 < \theta_U < 2.4$ and a wider region around $d_U \sim 3/2$ with

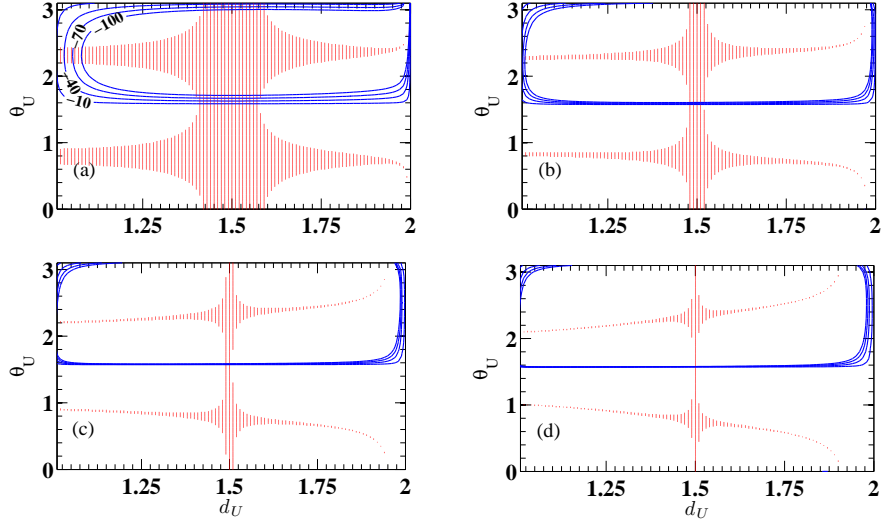


FIG. 2: (a)-(d) bound of Δm_{B_s} (scatters) and $-100 \leq A_{s\ell}^b 10^4 \leq -10$ (solid) for $|f_{sb}^R| = (4, 8, 12, 16) \times 10^{-6}$, respectively.

$\theta_U \sim 1.6$. For $|f_{sb}^R| = 8 \times 10^{-6}$, only $d_U \sim 1$ with $\theta_U \sim 2.2$ and $d_U \sim 3/2$ with $\theta_U \sim 1.6$ can have large $-A_{s\ell}^b$. As to other values of $|f_{sb}^R|$, they only happen at $d_U \sim 3/2$ and $\theta_U \sim 1.6$.

Similarly, we can use the same approach to study the influence of unparticle on the time-dependent CPA of Eq. (12). Taking the data $\phi_s = [-1.35, -0.20] \cup [-2.94, -1.77]$, i.e. $-1 < S_{J/\Psi\phi} < -0.2$ [41], we display the contour of $S_{J/\Psi\phi}$ as a function of d_U and θ_U in Fig. 3, where figure (a)-(d) corresponds to $|f_{sb}^R| = (4, 8, 12, 16) \times 10^{-6}$ respectively, the scatters stand

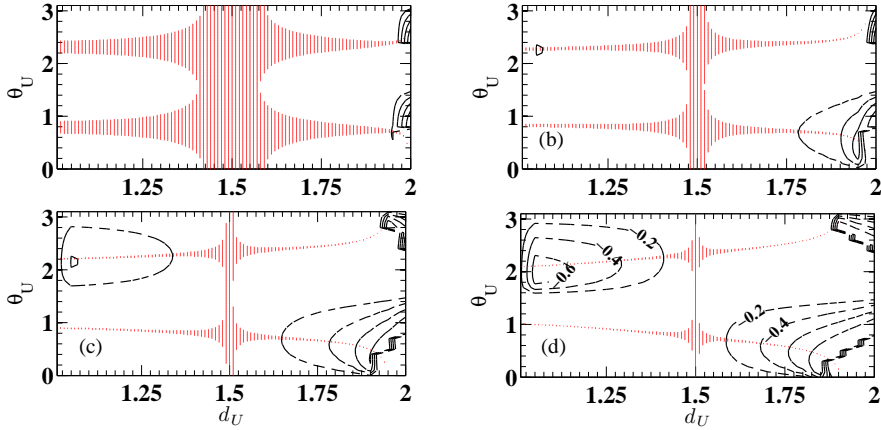


FIG. 3: The Legend is the same as that in Fig. 2 but for $-1 < S_{J/\Psi\phi} < -0.2$ (dashed).

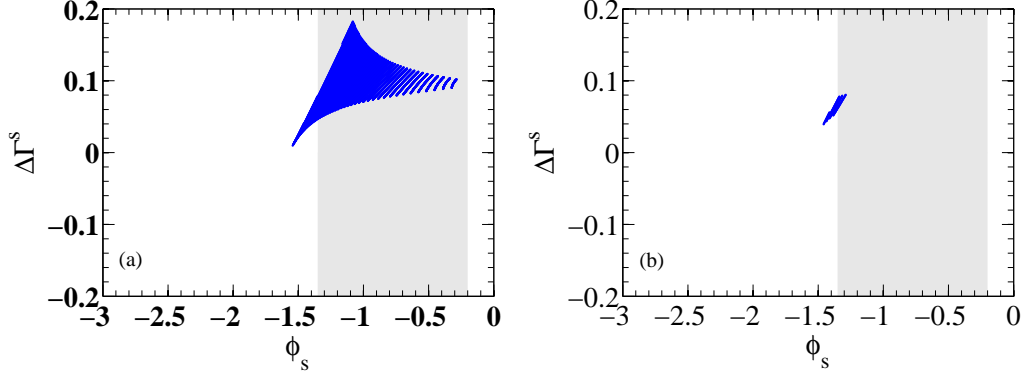


FIG. 4: (a)[(b)] Correlation of $\Delta\Gamma^s$ with ϕ_s for $f_{sb}^R = 4[8] \times 10^{-6}$, where the constraint of $(\Delta m_{B_s})^{\text{Exp}}$ with 2σ errors is included and $-100 < A_{s\ell}^b 10^4 < -10$ has been archived.

for the constraint of Δm_{B_s} and the dashed lines denote $-1 < S_{J/\Psi\phi} < -0.2$. By comparing Fig. 3 with Fig. 2, we find that large $-A_{s\ell}^b$ and $-S_{J/\Psi\phi}$ induced by the unparticle exchange cannot exist simultaneously. It is interesting if the peculiar results could be confirmed in the Super B factories, Tevatron and LHCb. Then, we would have more strong evidence to believe the existence of scale invariant stuff.

Beside the like-sign CA, $A_{s\ell}^b$, and time-dependent CPA, $S_{J/\Psi\phi}$, it is also important to study the correlation of $\Delta\Gamma^s$ with ϕ_s defined in Eq. (9). Thus, in terms of Eqs. (6), (9) and the definition $\phi_s = \arg(-M_{12}^s/\Gamma_{12}^s)$, the correlation between $\Delta\Gamma^s$ and ϕ_s resulted by the allowed values of d_U and θ_U that satisfy $(\Delta m_{B_s})^{\text{Exp}}$ with 2σ errors and $-100 < A_{s\ell}^b 10^4 < -10$ is presented in Fig. 4, in which the bands in the figure denote the data. We see that only the cases of $|f_{sb}^R| = (4, 8) \times 10^{-6}$ can be consistent with the current data of $\Delta\Gamma^s$ and ϕ_s when the bound of Δm_{B_s} is included and large $-A_{s\ell}^b$ is archived. By the figure, we learn that the smaller $|f_{sb}^R|$ owns a wider range of ϕ_s . This behavior could be understood from Fig. 2(a) and (b) where the available d_U in the former is much wider than that in the latter.

In summary, we have studied the peculiar phase of unparticle on M_{12}^q and Γ_{12}^q . In order to produce the unparticle efficiently at the LHC, we investigated the colored unparticle on the like-sign CA and time-dependent CPA with two scenarios of the free parameters chosen. In the scenario I, in which the involved CP phase is the same as that in the SM, the like-sign CA could be enhanced largely with the constraint of $S_{J/\Psi K_S}$ only. However, the CA

becomes suppressed when the constraint of Δm_{B_d} is taken into account. In the scenario II where the new CP phase is from the right-handed flavor mixing matrix, we find that $A_{s\ell}^b$ could be enhanced to the value observed by DØ, whereas the corresponding time-dependent CP cannot be enhanced to the range of current data. Additionally, the correlation between $\Delta\Gamma^s$ and ϕ_s could be consistent with current CDF and DØ results while the constraint of Δm_{B_s} is taken into account and $-100 < A_{s\ell}^b 10^4 < -10$ is archived.

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